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The Impact of Management on the Ground Flora Communities of Some Ancient Woods in the Wear Valley, County Durham.

By Clair Louise Holliday

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A dissertation submitted in part fulfilment of the requirements for the degree of Master of Science in Ecology by Advanced Method.

December 1994

- 6 NOV 1995

ABSTRACT

(i) The range of pH values under broadleaf plantations is more restricted than under different management types, this is restricted further under conifers.

(ii) Loamy soils under plantations were more acidic than under different management regimes.

(iii) Species distribution was found to be independent of aspect and slope, due to the narrow range of values for these variables.

(iv) Woods which contained areas of both clayey and loamy soils were found to be floristically richer than those woods which had one type of soil present.

(v) There is a reduction in species diversity under plantations, with conifer plantations having the lowest species diversity. Plantation forestry results in a monotonous sward of vegetation with little ecological interest.

(vi) Woodlands which have a hands off management regime are fairly poor floristically, but appear natural and have some ecological value.

(vii) Woods which are managed for conservation have the greatest diversity of species and have great ecological interest.

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ACKNOWLEDGEMENTS

I would like to thank the Durham Wildlife Trust, the owners of Frankland Farm and the National Trust for allowing me to use their woodlands in this study. Special thanks must go to Mr Barling and his staff at the National Trust offices at Scots Gap for invaluable assistance in researching the history of the Moorhouse Woods. Thanks also to Linda Drury at the Archives and Collections library at Durham University for her help in researching the history of Frankland Wood.

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A: INTRODUCTION

Modern farming practice has resulted in the grubbing out of many of our ancient woodlands for agriculture and the conversion of others to plantation. This study aims to investigate the effects of changing management practices on the ground flora communities of some ancient north east woodlands. Although many surveys have been undertaken in the south of the country (e.g. Peterken & Jones 1989, Pigott 1990), few have been carried out within the north east region. Most of the woodlands which have been investigated have had either a fairly recent change in management (i.e. within the last twenty to thirty years) with surveys undertaken to determine the effects of this change, or are undergoing cyclical management, such as coppicing, with surveys investigating the changes in the ground flora throughout the cycle.

The woodlands examined during this survey all have a similar management history, up to around the last one hundred years. The woodlands surveyed during this study are all ancient woodland sites from the mediaeval period and have been traditionally managed up until around the 1940's. Some of the sites are still actively managed, some neglected and others converted to plantation. The present survey aims to investigate the changes which have occurred within the woodlands using the ground flora communities as an indicator of management history. The results will indicate the best management techniques for the maintenance of the diverse flora found in our ancient north east woodlands.

Nomenclature follows Clapham, Tutin & Warburg (1962).

A:1 ANCIENT WOODLAND

Two historical types of woodlands have been recognised in Britain (Rackham 1980); primary and secondary woodland. Primary woodland refers to land which has remained wooded throughout recorded history. Secondary woodland refers to land that has been cleared and used as pasture, arable or for other purposes before reverting back to woodland. In practice, it is difficult to prove that a wood is primary unless pollen analysis is undertaken from deposits within the site. It is therefore necessary to recognise alternative but analogous categories namely ancient woodland which existed before an arbitrary year, usually 1600 AD, and recent woodland which came into existence on unwooded ground after this time (Peterken & Game 1984).

Ancient woodland may thus consist of both primary and secondary woodland but in unknown proportions (Peterken 1977). Another differentiation is that of natural and semi-natural woodland. Most woods are semi-natural in the broad sense that they owe their features to both man and nature (Tansley 1939). Natural woodlands would be those which have not been altered or managed by man in any way, none of which occur in this country. Tansley suggests that 'semi-natural' should be used to describe natural vegetation more or less modified by man and other stands which had been initiated by man but of a type which might naturally exist in the given environment.

A:1:a HISTORY OF BRITISH WOODLANDS

After several false starts after the last glaciation, Britain was successfully colonised by different trees which, over millennia, formed prehistoric forests called the wildwood (Rackham 1976). Much of Britain was covered in woodland at this time, with only areas which were unsuitable, such as coastal environments and marshy ground, uncolonised (Tansley 1965). Early authors (e.g. Leutscher 1969) believed that the wildwood consisted of a mixed oak forest, but recent pollen analysis (Rackham 1980) has shown that a complex mosaic of different kinds of woodlands, such as ashwoods, elmwoods and pinewoods existed, with oakwoods and hazel-woods predominating in the north and west of England and limewoods in the Midlands, east and south (Rackham 1985). Over time, man's activity has greatly affected the British landscape and has consequently altered much of the landscape to such an extent that few wooded areas remain.

Human influence on the landscape extends as far back as the earliest post-glacial, and the destruction of the wildwood continued throughout the Neolithic and Bronze Ages and beyond. Up until the Romans, most of the destruction had been mainly restricted to the south east but, with the Romans came great forest clearances further north, as England and Wales developed into one of the chief agricultural and corn-exporting lands of the classical world (Rackham 1976). By the time of the Norman Conquest of 1066 AD, the Anglo-Saxons had cleared any wildwood left intact by the Romans.

From the Norman invasion in 1066 and forwards, large proportions of many counties were laid waste and the agricultural wealth of the country greatly decreased. However, the event would hardly have affected the natural vegetation except for local damage by fire (Tansley 1965). The Normans protected large areas of forest as Crown land with the creation of many Royal Forests.

Even when regarded simply as hunting grounds, woodland at this time was already becoming scarce enough to warrant protection (Edlin 1970). These forests were at their maximum by the middle of the twelfth century and some estimates suggest that up to one third of the country was Royal Forest at one time, though these were mainly concentrated in the south of England (Cantor 1980). An expansion of cultivation accompanied by an increase in deforestation followed, continuing through the twelfth century and proceeding through the Middle Ages. Although slow, the cumulative effects were great. By around 1334 the area of Royal Forest in the country as a whole had shrunk to around two thirds of what it had been in 1250 (Cantor 1980).

Forest management also changed during the Middle Ages with the exploitation of English oakwoods as coppice with standards being established (Tansley 1965). Felling of the large forest trees would have led to an increase in the area of open woodland, resulting in the increase of hazel and other shrubs. This more open woodland would have consisted of spreading trees with a continuous shrub layer below which would respond to regular coppicing at intervals of 10-15 years. This became the standard method of forest management and was continued for many centuries, up to the beginning of the twentieth.

During the sixteenth century there was an increasing shortage of timber, especially for ship building, even though the midlands were still fairly well wooded, and in 1544 statutes demanded that there were at least 12 standard trees per acre of woodland (trees which were allowed to mature to full size and then felled for timber). However, the timber shortage continued and by the middle of the seventeenth century wood as a form of fuel was only available to the wealthy, marking the definitive exhaustion of the last forest reserves. Some of the remaining woodlands were used for charcoal and tanning and were usually converted into pure coppice with the remainder neglected, consisting of a large proportion of deformed and decaying trees (Rackham 1985).

During the eighteenth century there was a rapid increase in the population, putting more pressure on the woodlands for fuelwood, farmland and dwellings. This pressure abated in the nineteenth century and woodmanship fell into decline, probably due to the railways bringing cheap coal into the countryside (Rackham 1985). The reduction of woodlands in general was recognised at the beginning of the nineteenth century and planting schemes were initiated, though these were still being implemented in the 1870's (Kain & Prince 1985).

The pressure on the forests increased during the nineteenth and twentieth centuries, as further changes occurred due to the rapid industrialisation of the nation, especially in the Midlands and in the North of the country. 450,000 acres of woodland were removed for the war effort during the great war and although a major replanting scheme started post-war under the Forestry Commission which was formed in 1919, these woodlands were mainly plantations of non-native trees which completely altered the character of the landscape in many parts of the country. A further 373,000 acres were clearfelled during the second world war (Locke 1987). The trees were taken mainly from privately owned woodlands as the trees planted at the end of the first world war would not have been sufficiently mature.

Within the past 100 years there have been new threats to our woodland heritage including increased taxation, death duties, lack of maintenance and clearance, due to an increasing population (Leutscher 1969). Nevertheless, most fragments of ancient woodlands remained in existence until 1945 (Rackham 1985) and in 1947 more than two thirds of all coppice still contained standard trees. By 1947 there was nearly three and a half million acres of woodland, of which 350,000 was coppiced (Locke 1987). Three decades of unprecedented destruction followed and immense areas were converted to farmland or plantation. Between 1945 and 1975 between a third and a half of the remaining ancient woodlands were destroyed (Rackham 1980).

A:1:b THE IMPORTANCE OF ANCIENT WOODLANDS

Since the end of the first World War total forest cover has increased from 3 to 11% of the total land area (Morgan *et al* 1992), chiefly by the increase in monoculture plantations. However, the area of ancient woodland has rapidly decreased during this time. Peterken (1981) estimated that 574,000 ha. of British woodland was ancient woodland. This estimate included sites which had been replanted, either part or whole. He estimated that ancient woodlands make up a relatively small proportion (*c.* 28%) of the total woodland area.

A more recent survey by the Nature Conservancy Council (now English Nature) published in 1992 (Spencer & Kirby) estimated that today, ancient woodland covers about 2.6% of England and 2.7% of Wales. Some 7% of those ancient woodlands present in *c.* 1930 have been grubbed out, while 38% have been replaced by plantations.

The report surmised that ancient woodland has become highly fragmented over the country, with 83% of sites less than 20 ha., whereas less than 2% of ancient woodlands are greater than 100 ha.. Most of the ancient woodland area (64%) nevertheless occurs in woods over 20 ha..

Peterken (1977) stated that 'woodlands harbour an immense variety of wildlife, constitute the original source of many species in other habitats, and probably include sites which have been continuously occupied by the climax formation since man first started to modify vegetation'. The richness found in woodlands is due to the specialised environmental conditions which exist in these habitats. The degree of light filtering through to the forest floor through the tree canopy is a main controlling factor on woodland plants, providing conditions which results in the wide variety of ground flora communities found in British woodlands over the seasons of the year.

The shelter provided by the trees against drying winds, excessive sunshine and extremes of temperature allows a great profusion of woodland plants. The trees also provide a rich leaf litter and their roots bind the soil, creating a nutrient rich, stable environment in which to grow. All these factors help to maintain a rich flora, not only among the higher plants but also among the lower forms such as mosses, ferns and fungi (Leutscher 1969).

The richest woodland sites tend to be those that have been continuously wooded for the longest time (Peterken & Game 1984), with many species of plants and animals, often the rarer species, preferentially associated with areas which have been wooded for a long period (Peterken 1974). Ancient woodlands have a specialised plant community (Rackham 1980). There are a range of plants which are indicators of ancient woodland and even after several centuries, new woodlands have often not acquired the whole range of these characteristic plants (Rackham 1985). These species would historically have been widespread across the landscape but due to climate and land use changes, over time have now become largely restricted to ancient woodlands. A list of fifty such species have been recorded for Lincolnshire alone (Peterken & Game 1984), though the species list varies not only between counties, but also within counties, such is the nature of some of these species. Some species are common in some counties and are not considered to be indicators of ancient woodlands, while in others they are found only in woodlands which have been present for several hundred years.

Several tree species are also restricted in being present only in ancient woodlands, including the service tree (*Sorbus torminalis* Linnaeus.) and lime (*Tilia sp.* L.). These species will not colonise new woodlands and rarely appear in secondary woodlands, even after centuries have elapsed (Rackham 1985). Many occurrences of sessile oak (*Quercus petraea* Liebl), for example, are associated with ancient royal forests (for example, Epping and the New Forest) and many stands of this species appear to represent the descendants of ancient populations which are unlikely to have been disturbed by planting.

Relic features conserved within an ancient woodland may include earth banks, ditches, pollarded trees and coppice stools, as well as ancient hedges and walls. The woodland soil is often undisturbed, providing a historical record of land use and climate changes. These soils are of scientific importance since they show the natural pedogenic cycles and trends in areas where woodland is the climax vegetation (Ball & Stevens 1980-1).

Ancient woodlands have a high amenity value as nature reserves, parks etc. and are once again being used as a source of timber and fuel (Rackham 1985). Past management practices have also been revived, such as coppicing and pollarding and detailed surveys undertaken in order to determine the history of these woodlands, along with their distinctive floral communities.

The management of all woods, including woods which have been managed as wood pasture, royal hunting forests, coppice or coppice with standards, chases and deer parks changes the whole character of a woodland for many years to come, with the past management affecting the present communities (Leutscher 1969). Woods have been moulded by human influence over many centuries and that influence is just as strong, perhaps even stronger today (Morgan 1987).

A:1:c NATIONAL SETTING

The Enclosures Acts of the eighteenth and early nineteenth centuries resulted in a fundamental change in the character of the landscape of lowland Britain and the emergence of an agricultural landscape pattern of hedgerows associated with isolated trees and copses. The effects of enclosures can be seen in County Durham, where the remaining semi-natural woodland is generally confined to slopes, particularly valley sides and on land unsuitable for agriculture or commercial woodland (DCC Structure Plan).

The Forestry Commission report of 1984 estimated that 5.7% of County Durham is wooded (13,934 hectares). Ancient woodland covers 4,117 ha. of the county, with only a small amount of ancient woodland (42 ha.) cleared since around 1930. This is small compared to the amount removed in other counties since this date. Durham County Council view trees as having a major role in the landscape, not only providing screens and shelter but also for visual amenity and their role in providing natural habitats in the county. Woodland is one of the elements which constantly re-occurs in the higher quality landscapes as defined by the county council.

The study aims to investigate the changes which have occurred in some of the ancient woodlands of County Durham and although it examines only a small proportion of the ancient woodland in the county (*c.* 1%), the study will form a basis for further investigation and aims to provide information indicating the most appropriate management regime for the ancient woodlands in the north east.

A:2 SITES & STATIONS

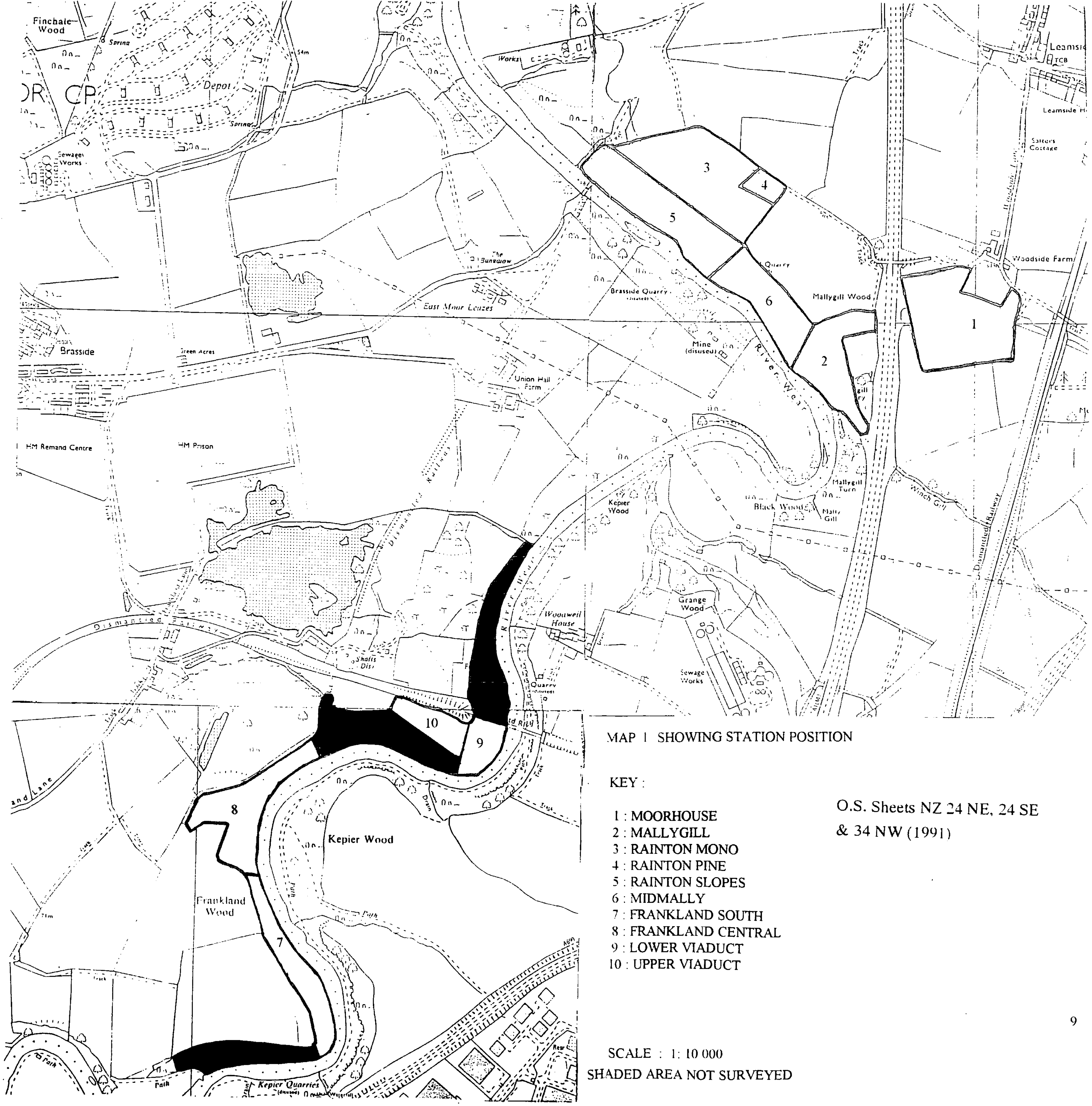
Woodlands which had been shown to be ancient woods by document records were selected from within Durham County. It was considered appropriate to start with sites closest to the University where the research was based. The close proximity of the sites to each other was considered to be an important factor in order to minimise the possible variation in environmental conditions between the sites. The woods selected for this study are all semi-natural ancient woodlands dating from the mediaeval period.

The Moorhouse complex, consisting of Moorhouse, Mallygill and Rainton Park Woods, is situated on the north east side of the River Wear, about 4 miles, north east of Durham city. Frankland Wood is situated approximately 3 miles north east of Durham on the opposite bank of the Wear and is part of the estate including Frankland Farm (Map 1). The Moorhouse complex lies within an area designated as being of great landscape value by Durham County Council and is designated as a site of particular ecological importance. No woodland within the Moorhouse complex is designated as a Site of Special Scientific Interest (SSSI) at present, though the National Trust estate advisory office in Cirencester believes that the woods are well worth SSSI status (Poad 1991).

After an initial visit, the woodlands were divided into stations, in order to distinguish different areas within the woods. The Moorhouse complex was split up according to management history since this was well documented and known at the time. Frankland Wood was divided up by differing canopy and flora characteristics since at the beginning of this study little was known about the history of management at this site. The four woodlands were divided into ten stations (see Table 1 & Map 1).

Table 1 : Sites and Stations.

GRID REFERENCE	SITE	STATION
NZ 310460	Moorhouse Wood	Moorhouse
NZ 306459	Mallygill Wood	Mallygill
NZ 303463	Rainton Park Wood	Rainton Mono
NZ 304463	" " "	Rainton Pine
NZ 302463	" " "	Rainton Slopes
NZ 305460	" " "	Midmally
NZ 291443	Frankland Wood	Frankland South
NZ 291447	" "	Frankland Central
NZ 297449	" "	Lower Viaduct
NZ 296449	" "	Upper Viaduct



MAP 1 SHOWING STATION POSITION

KEY :

1 : MOORHOUSE
2 : MALLYGILL
3 : RAINTON MONO
4 : RAINTON PINE
5 : RAINTON SLOPES
6 : MIDMALLY
7 : FRANKLAND SOUTH
8 : FRANKLAND CENTRAL
9 : LOWER VIADUCT
10 : UPPER VIADUCT

O.S. Sheets NZ 24 NE, 24 SE & 34 NW (1991)

SCALE : 1: 10 000

SHADED AREA NOT SURVEYED

Although the woodlands in this study have been similarly managed in historical times, in the last fifty years the differing management regime has resulted in wide variations in the floral communities of the woods. Within a single woodland there have been different management techniques (Table 2), the results of which will be discussed later.

Table 2 : Station summary of management history.

STATION	MANAGEMENT
Moorhouse	Active
Mallygill	Active
Rainton Mono	Plantation
Rainton Pine	Plantation
Rainton Slopes	Active
Midmally	Active
Frankland South	Little
Frankland Central	Little
Lower Viaduct	Little
Upper Viaduct	Plantation

A:3 PHYSICAL CHARACTERISTICS

A:3:a GEOLOGY, GEOMORPHOLOGY, TOPOGRAPHY AND SOILS

The geology of the area is that of the middle coal measures of the Upper Carboniferous (Smith & Francis 1967). The river, which forms the south west boundary of Rainton Park and Mallygill Wood and the north east boundary of Frankland Wood cuts into the sandstone beds within the coal measures. The drift geology of the Moorhouse complex is that of boulder clay with some patches of alluvium along the river, which is especially noticeable where Mallygill exits into the slow flowing Wear. The vertical sandstone exposures present in Mallygill Wood, set back from the River Wear are as a result past quarrying activities. The drift geology of Frankland Wood is boulder clay with some glacial gravels. The soils in the area are Dunkeswick, a breakdown of till from the Palaeozoic and Mezozoic sandstones and shales. The soil is slowly permeable and is seasonally waterlogged.

The elevation of the Moorhouse complex varies from 25 m OD at the banks of the River Wear to 56 m OD at the top of Rainton Park Wood and is predominantly south west facing. The riverside section of the site is fairly steep in places, especially the valley of the Mallygill and the area of woodland adjacent to the quarried area on the Rainton Park slopes. Moorhouse Wood is fairly flat, as is the north east section of Rainton Park Wood. The elevation of Frankland Wood varies between 25 and 50 m OD. The site is predominantly south east facing. The riverside areas are relatively flat with the ground sloping up to the fields to the west of the woodland. The slope is not as steep as the slopes of the Rainton Slopes and Mallygill stations.

A:3:b HYDROLOGY

The most obvious hydrological feature affecting the sites is the River Wear, a wide, moderately flowing major river. The river is liable to very large fluctuations in height and often floods the footpaths along the river in the Moorhouse complex. Two streams pass through Moorhouse complex into the Wear; the Mallygill, a small fast flowing stream which passes through Moorhouse Wood, under the A1(M), through the Mallygill site (at which point, the bed becomes cobbled) to the River Wear. The cobbling of the stream bed was undertaken several hundred years ago when it was a cart track up to Moorhouse Wood, before becoming the bed of the stream. The Winch Gill, a small stream, passes from the south east corner of Mallygill Wood northwards towards the Mallygill stream, converging with the Mallygill at the same point where they meet the River Wear.

A:4: HISTORY OF WOODLAND MANAGEMENT

A:4:a HISTORY OF THE MOORHOUSE COMPLEX

The Moorhouse complex is a mediaeval woodland which belonged to Durham Priory and then to the Durham Dean and Chapter and would have been historically managed as a coppice with standards woodland. The area towards the river (i.e. Rainton Park and Mallygill Woods) show evidence of ditch and bank with the trace of a wall towards the bottom of the steep slope of Rainton Park, towards the river (Rainton Slopes). These earthworks are fairly typical of woodlands which have been used as deer parks during the mediaeval period.

There is evidence of past coppicing in the Rainton Park and Mallygill Woods, where large small leaved lime (*Tilia cordata* Miller) coppice stools still remain, dated to at least the seventeenth century, possibly earlier. Moorhouse Wood is an ancient woodland, but, much of the interest has been lost through eighteenth century felling and replanting. The complex is said to be present on a small scale map of 1570, held in the Palaeography department of Durham University. The name 'Morehouse' appears on Robert Moreden's county parks map of 1695, indicating that the woodland was still being managed as a park at this time (Chapman 1977). Its boundary appears on Armstrong's map of 1776 but no tree symbols are shown. The complex is shown as part plantation and part wood on the 1846 Tithe plan (Baker & Tate 1868).

The Moorhouse complex; a total of 24.67 hectares, was bequeathed to the National Trust in 1945 by the trustees of the Moor House Estate of George Fenwick Boyd, with the mineral rights retained by the estate. The whole property was declared inalienable in 1947. Part of the complex (9.3 square yards) was compulsory purchased in 1971 for the construction of the A1(M), dividing the complex into two. At around the same time, the newly separated area (8.3 ha..) was let to Durham County Conservation Trust Ltd., now known as the Durham Wildlife Trust, to be managed as a nature reserve (Moorhouse wood).

A:4:a:i MOORHOUSE WOOD

Virtually all of the area known as Moorhouse Wood has been worked over for coal in the past. There is a large concentration of shallow circular depressions, some water filled, fringed by low spoil heaps which are characteristic of early shallow shaft workings (bell pit workings). These are probably dated from the seventeenth century or earlier, with the pattern suggesting that the coal is close to the surface since the pits do not appear to follow the line of any seams.

Moorhouse Wood was partially thinned and pruned in 1950 and a thinning and replanting programme has been carried out by the Trust since at least 1972 in order to promote the growth of standards. The area was badly disturbed during the miners strike of 1983 where much tree and bough removal took place. Today, due to repeated disturbance Moorhouse shows little evidence of past coppice management.

A:4:a:ii RAINTON PARK WOOD

The plateau areas of Rainton Park Wood were clearfelled as part of the War effort. The plateau was supposedly replanted around 1945, predominantly with *Quercus petraea* (Rainton Mono), but with a small section planted with *Pinus nigra* L. (Rainton Pine). This has resulted in an even aged woodland which consequently is poorly structured. There is, however some controversy as to whether Rainton Park was replanted or was subject to natural regeneration after clearfelling. The head forester at the time has always denied that the area was replanted and there are no financial records of any plants being bought for replanting, but the even aged nature of the canopy and the lack of understorey suggests that the area was planted. Thinning of the Rainton Park and Mallygill Woods took place in 1952, whilst a fire in 1977 destroyed a considerable area of woodland, though the precise location of this is unknown.

A:4:b HISTORY OF FRANKLAND WOOD

Frankland Wood was part of the Durham bishopric estates and first record of the wood is found in Hardy where there is an account of ratification of a lease of herbage in 'Fraunkeleyn' park, dated 1341. The wood of 'Frankeland' was sequestered for the use of the state in 1645 and rented out for monies to support the civil wars (Surtees Society 1905). Few early maps of the woodland can be found, but from the Survey Atlas of England and Wales of 1939 it can be seen that Frankland Wood was substantially larger than it is today, extending further away from the river at the northern section of the wood.

On Robert Moreden's County parks map of 1695 the land opposite Kepier Park is called Croke Hall, of which the woodland would have been a part. Few details about the woodland up to the present day are available, but the ancient nature of the woodland was confirmed by a search of the documents in the Archive Collection of Durham University. Due to the difficulties in accessing the site, little management is undertaken in the wood. This is especially so on the slopes leading up to the arable fields of Frankland farm, where much dead standing timber remains. Only light management has taken place in the woodland for at least the past fifty years, apart from the oak plantation at the Upper Viaduct station, planted about fifty years ago. More recently, felling of some large beech trees (*Fagus sylvatica* L.)on the flat areas of Frankland Central has taken place with the timber left lying on the forest floor.

A:5: FLORA

A:5:a FLORA OF THE MOORHOUSE COMPLEX

Moorhouse Wood is a small deciduous wood which has seen considerable regeneration from stumps cut during the 1939/45 war, producing a coppice effect. It is densely wooded with a heavy undergrowth giving it a rather dark appearance from within. The woodland is very mixed and has a more or less semi-natural appearance, but lacks mature and overmature trees. It still has a quite varied structure containing native and non native trees, with *Q. petraea* dominant, *Acer pseudoplatanus* L. forming an important part of the canopy and *Ulmus glabra* Hudson and *Fraxinus excelsior* L. among the more common species. The understorey is well developed in places and sparse in others with dominant species including *Crataegus monogyna* Jacq. and *Corylus avellana* L.. *Lonicera periclymenum* L., *Ilex aquifolium* L. and *Sambucus nigra* L. are also present.

The ground flora in the woodland is very varied, with *Mercurialis perennis* L., *Anemone nemorosa* L. and *Oxalis acetosella* L. scattered throughout, and patches of *Galium odoratum* Scop., *Allium ursinum* L. and *Geum urbanum* L.. Grass species include *Milium effusum* L. and *Holcus lanatus* L.. The wood is semi-natural but shows a number of unusual features including populations of *Carpinus betulus* L. and *Fagus sylvatica* whose origins are still unclear. These species along with *Rosa arvensis* Hudson have been suggested to be over two hundred years old.

Rainton Park Wood consists of a *Q. petraea* plantation with a small area of *Pinus nigra* on the plateau and mixed woodland on the slope leading down to the river. The plateau canopy is dominated by *Quercus*, with *Betula pendula* Roth, *Sorbus aucuparia* L. and *Acer pseudoplatanus* also present. The plateau area has little understorey present due to the even aged nature of the site. The ground flora is also limited, with few species present. *Holcus mollis* L. is abundant with scattered patches of *Pteridium aquilinum* Kuhn, *Rubus fruticosus agg.* L. and *Lonicera periclymenum.*

Mallygill Wood is a semi-natural woodland, oak dominated, with a wide variety of other species such as *Acer, Fraxinus* and *Fagus* also present. Many species form only a small part of the canopy; these include *Ulmus procera* Salisb., *U. glabra, Sorbus aucuparia, Tilia cordata* and *Castenea sativa* Miller. *Crataegus* is the dominant constituent of the understorey and is accompanied by *Sambucus nigra* and *Lonicera*. The ground flora is abundant and varied, with *Luzula sylvatica* Hudson, *Rubus, Oxalis, Mercurialis, Anemone nemorosa, Stellaria graminea* L. and *Hedera helix* L.. The dominant grass is *H. mollis* with patches of *Melica uniflora* Retz. and *Deschampsia flexuosa* Trin. in places.

The mixed woodland on the slopes of Rainton Park and Mallygill are considered to be the most interesting part of the Moorhouse complex since the steeper parts are ancient semi-natural woodland which is at least 400 years old. The dominant canopy species is *Quercus* with *Betula, Sorbus* and *Acer* also present. The understorey consists of *Corylus, Ilex* and *Crataegus.*

The section of woodland running along the side of the wear valley southwards from the quarried area of Mallygill, extending up the Mallygill stream has a very unusual woody composition. This area includes formerly coppiced *Fagus sylvatica* and *Carpinus betulus*, with stools which appear to be around 300 years old. *Ulmus glabra* and *Tilia cordata* are also found in the same stand with old *Tilia* coppice stools present on the steep slopes, which have been estimated at between 3 and 400 years old, representing one of the very few sites in northern Britain where small leaved lime is believed to be native and not planted. Rackham suggests that *Tilia, Fagus* and *Carpinus* may all be native to the site since their presence predates any ornamental planting (B. Huntley, *pers. comm.*). The ground flora of this area consists of *Rubus, Dryopteris dilatata, Lonicera, Luzula* and *Stellaria graminea* with *Holcus mollis* and *Deschampsia flexuosa* the dominant grasses.

Rosa arvensis has been recorded in both Rainton Park and Mallygill Wood and as such is present at one of only a few localities in Northern England. Additional features of interest within this area is the presence of small areas of heath amongst open woodland above Mallygill Craig and the quarry, though this area was not included in the present survey.

A:5:b FLORA OF FRANKLAND WOOD

Frankland Wood is oak dominated and contains an oak plantation at the Upper viaduct station. This station has a even canopy and is poorly structured with little understorey and a limited ground flora. The only other canopy species found in the plantation area is *Acer pseudoplatanus* and the ground flora of this area is dominated by *Deschampsia flexuosa* and *Pteridium aquilinum*. The canopy of the rest of Frankland Wood is varied, with pockets of very old beech (especially in the south of the woodland), estimated to be several hundred years old. Other canopy species include *Acer pseudoplatanus* and *Ulmus glabra*. The understorey consists of *Ilex aquifolium, Corylus avellana* and *Sambucus nigra.*

The ground flora of Frankland Wood varies between the northern and southern parts of the wood with the northern section containing *Deschampsia flexuosa* and *Pteridium aquilinum*, with patches of *Oxalis acetosella* and *Mercurialis perennis.* This area has an open canopy with a varied, if sparse ground flora with large amount of litter present. There are also a number of extremely large trees present, especially birch, oak and beech. This station has an unnatural quality to it though this is difficult to define, the greatest anomaly being the large amounts of litter present. Normally litter is relatively quickly broken down into humus, but in this area the litter layer is quite thick and covers a large area of the forest floor. The southern areas of the woodland are dominated by *Rubus fruticosus, Dryopteris dilatata* and *Holcus mollis* with patches of *Lonicera periclymenum*, *Stellaria holostea* L., *Galium aparine* L., *Luzula sylvatica* and *Pteridium aquilinum*.

B: METHODS

B:1 SITE INVESTIGATION

B:1:a CANOPY AND GROUND FLORA

The site investigation took place between mid May and mid July 1994. The canopy was investigated using the point centred quarter method (PCQ), a plotless sampling technique (Cottam, Curtis & Hale 1953). For each station a rough map was drawn up, with the PCQ's sited as evenly as possible within. These maps were adhered to as closely as possible during the site work in order to describe the canopy characteristics as fully as possible. Each PCQ was positioned so it was at least 30 metres from another one, which allowed a gap of at least 10 metres between each PCQ. This allowed a maximum number of trees to be sampled since it reduced to degree of overlap of tree species between PCQ's. For the few trees which occurred in two PCQ's, the mean distance to the tree was calculated and the total number of trees in the calculations was reduced by one for each replicant tree. This method allowed an intermediate tree density to be calculated.

Depending on the size of each station, between one and five PCQ's were undertaken at each station (Table 3). In accordance with standard procedure, the minimum girth to be recorded was 10 cm, which was recorded at breast height (1.4m). The nearest four trees around the quarters of a compass (N-E, E-S etc.) were recorded for girth, distance from the arbitrary centre and tree species. From this central PCQ four others were taken at 10m from the arbitrary centre in the directions NE, SE, SW, and NW, in order to provide a more representative sample of the canopy in the area. This was repeated for all the PCQ's in each station.

A 2x2 metre quadrat was taken at the centre of each PCQ and surveyed using the Domin Scale for cover/abundance measurements (Table 4). Up to five further quadrats were surveyed at each station in order to allow for any variations in the ground flora which were not accounted by the quadrats surveyed during the PCQ analysis (Figure 1). Species were identified using Rose (1981), Fitter *et al* (1992), Jermy & Camins (1991), Smith (1980) and Humpries *et al* (1981).

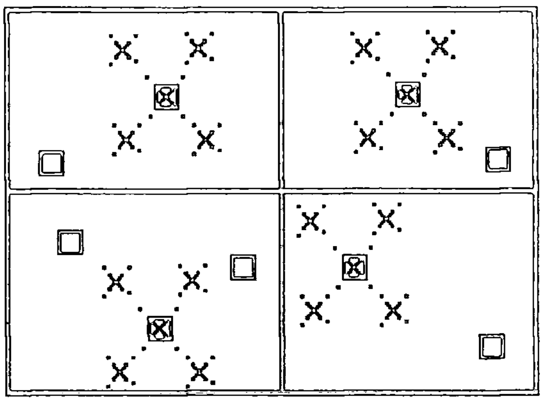
Table 3 : Total number of extra quadrats and PCQ's for each station

STATION	No. OF PCQ'S.	No. OF EXTRA QUADRATS
Moorhouse	5	4
Mallygill	5	5
Rainton Mono	5	4
Rainton Pine	1	1
Rainton Slopes	5	3
Midmally	5	5
Frankland South	3	3
Frankland Central	3	4
Lower Viaduct	2	2
Upper Viaduct	2	1

Table 4 : The Domin Scale for Cover/Abundance.

DOMIN SCALE	SPECIES COVER	
1	< 4 %	1-2 Individuals
2	< 4 %	Scattered Individuals
3	< 4 %	Individuals Frequent
4	4 - 10 %	
5	11 - 25 %	
6	26 - 33 %	
7	34 - 50 %	
8	51 - 75 %	
9	76 - 90 %	
10	91 - 100 %	

Figure 1 : Showing the distribution of PCQ's and quadrats within a station.



B:1:b SOIL

The soil investigation consisted of a description of soil type and pH measurements. Due to the unreliability of portable pH meters, a small sample of soil was taken from just below the humus layer from the centre of each quadrat, refrigerated overnight and tested within 24 hours of collection. An electronic meter was used to determine pH after calibration using solutions of pH 4.0 and pH 7.0. Approximately 15g of soil was mixed with an approximately equal amount of distilled water, stirred until well mixed, allowed to stand for a few minutes to allow the larger particles to drop out of suspension and then tested for pH to one decimal place.

B:2 DATA ANALYSIS

B:2:a DECORANA (Detrended correspondence analysis, or DCA)

For each quadrat, tree species, individual frequency, density, basal area as well as total density and total basal area were collated. For those quadrats which did not have a PCQ associated with them, the average frequency, density and basal area for all the tree species present in the canopy for the station were compiled. The average total density and average basal area were also determined for these quadrats. The PCQ information collected was analysed using DECORANA, an updated form of reciprocal averaging (Ter Braak 1987). This is an extension of Cornell Ecology Program DECORANA (Hill 1979a), which has been refined in order to avoid the problems of arch distortion and compression at the end of the axes (Hill & Gauch 1980).

The program extracts the principle axes of variation within the data set. Although subsequent axes may show other environmental gradients, they usually prove less useful than the first axis. Some samples and species can greatly distort the analysis, affecting the pattern in the canopy described by DCA analysis. It is often samples and species rare in the data set which distort the analysis (Malloch 1988) and Malloch advises that these be omitted. The four axes were plotted in order to determine those species and samples distorting the analysis, since these appears as outliers in the graphs. These samples and species could then be downweighted in a rerun of DCA. The axes resulting from the second DCA were then placed within the environmental variable file for canonical analysis.

B:2:b CANOCO (Canonical correspondence analysis, or CCA)

CCA (Hill 1979b) is a combination of ordination and multiple regression analysis (Ter Braak 1988). This technique is based on the assumption that species distribution is not random, but is linked to the environmental conditions prevailing within the stations. It explains the floristic variations by ordination which is constrained by the combination of environmental factors present. The results of the analysis are displayed as environmental biplots where the influence of the environmental factors on the quadrats are represented as arrows; the length and direction indicating the degree of influence these variables have on the patterns exhibited by the principle axes. A full explanation of CCA may be found in Ter Braak (1987).

Two files were created for use in CCA : an environmental variable file and a species file. The CCA environmental file consisted of a quadrat listing, together with the site in which the quadrat was placed, soil type, soil pH, slope, the four DCA canopy axes and the aspect of each quadrat. The sine and the cosine of the aspect were used in order to minimise the variation in the data (for example, 355° and 5° are only 10° apart but the analysis would place them at either end of an axis of variation).

The species file contained the species codes and scales determined by the PREPARE program, which condenses the NVC and Domin data for use in CCA. The species file and the environmental file were analysed using CCA in order to examine the effects of the different variables measured in the ground flora community present within each quadrat and also at each station.

C: RESULTS

C:1 pH ANALYSIS

Table 5 : pH results.

STATION	pH RANGE	AVERAGE pH	SOIL TYPES PRESENT
Moorhouse	4.0 - 7.2	5.20	Clay & Loam
Mallygill	3.9 - 6.4	4.95	Clay & Loam
Rainton Mono	3.8 - 4.2	4.05	Loam
Rainton Pine	4.0 - 4.2	4.10	Loam
Rainton Slopes	3.8 - 4.8	4.10	Loam
Midmally	3.8 - 5.5	4.40	Clay & Loam
Frankland South	3.8 - 4.4	4.05	Loam
Frankland Central	3.7 - 4.0	3.90	Loam
Lower Viaduct	3.8 - 5.3	4.25	Loam
Upper Viaduct	3.6 - 4.0	3.80	Loam

From Table 5 it can be seen that those stations which have a wide pH range are the Moorhouse, Mallygill, Midmally and Lower Viaduct stations. The first three of these stations all contain areas of clayey soil. Soil samples taken from quadrats on clayey soil in general have higher pH's than those taken on loamy soils (Appendix 1). The Lower Viaduct station does not contain any areas of clayey soil, but does have a wide range in pH measurements. This is possibly due to the large amount of disturbance which would have taken place when the viaduct was built.

It can also be seen from the above table that in general, those stations with a narrow range in pH are those stations which contain plantations (the exception being Frankland Central, which, as will be seen later is part of a woodland which is difficult to explain). Rainton Pine, the conifer plantation has the most restricted range in pH.

Since the effects of management are to be examined in this study it was decided to examine the effects of changing management on soil pH, while allowing for the variability in soil type (Table 6).

Table 6 : Site Character Grouping

CHARACTERISTICS	pH RANGE
Clay & no Plantation	3.8 - 7.2
Loam & no Plantation	3.8 - 5.3
Plantation & Loam	3.8 - 4.2

Unfortunately no sites were surveyed which contained plantations on soils which were clayey, but it can be seen that the effects of planting on loamy soils is to restrict soil pH to a much narrower range. This study examined relatively few woodlands, but if this trend were to continue on examination of further sites, then a reduction in the floral diversity of woodlands which had plantations within them would be expected, due to the reduced diversity in environmental conditions.

C:2 GROUND FLORA

Table 7 : Number of species present at each station.

(Note : * denotes that the station is under plantation management)

STATION	No. OF UNDERSTOREY / TREE SEEDLINGS	No. OF GROUND SPECIES	TOTAL
Moorhouse	6	30	36
Mallygill	11	37	48
Rainton Mono *	4	13	17
Rainton Pine *	1	4	5
Rainton Slopes	7	19	26
Midmally	9	23	32
Frankland South	4	12	16
Frankland Central	4	12	16
Lower Viaduct	6	19	25
Upper Viaduct *	4	5	9

For a full species list for each station, see Appendix 2.

The results from Table 7 indicate that Frankland South, Frankland Central, Rainton Mono, Rainton Pine and the Upper Viaduct stations all have very low numbers of species present. Of these, all but the Frankland South and Frankland Central stations are plantations, with these two stations classed as poorly managed woodlands. The station which had been planted with conifers has approximately one third of the species which are found in plantations of deciduous trees. Those stations which were actively managed have a rich and varied ground and understorey composition.

The 'hands off' method of management practised within the Frankland South and Central stations has resulted in the reduction in the number of ground flora species to the point where these stations are comparable to those which have undergone intensive, recent management in the form of plantations. However, the ground flora present within the poorly managed woodlands did appear natural, with a mosaic of different ground flora communities. The ground flora found under the areas of plantation was considered to be a monotonous sward of uninteresting vegetation with little ecological value.

The impression gained during this study as to the effects of plantation on the ground flora was that under plantations there was a much reduced range of species present, with the lowest number of species found under conifer plantations. Those stations which had little management also had a reduced ground flora, but were at least natural in appearance. Those stations which were actively managed had a varied understorey composition, coupled with a diverse ground flora.

C:3 DCA ANALYSIS

DCA was used to determine the patterns in the canopy along the four most important gradients, the first axis representing the environmental gradient which has the greatest effect on the species distribution. DCA was used to determine those species and samples which were distorting the analysis, which appeared as outliers when the axes were graphed. Those species and samples which were distorting the analysis would then be removed, resulting in an overall description of the canopy for use in further analysis.

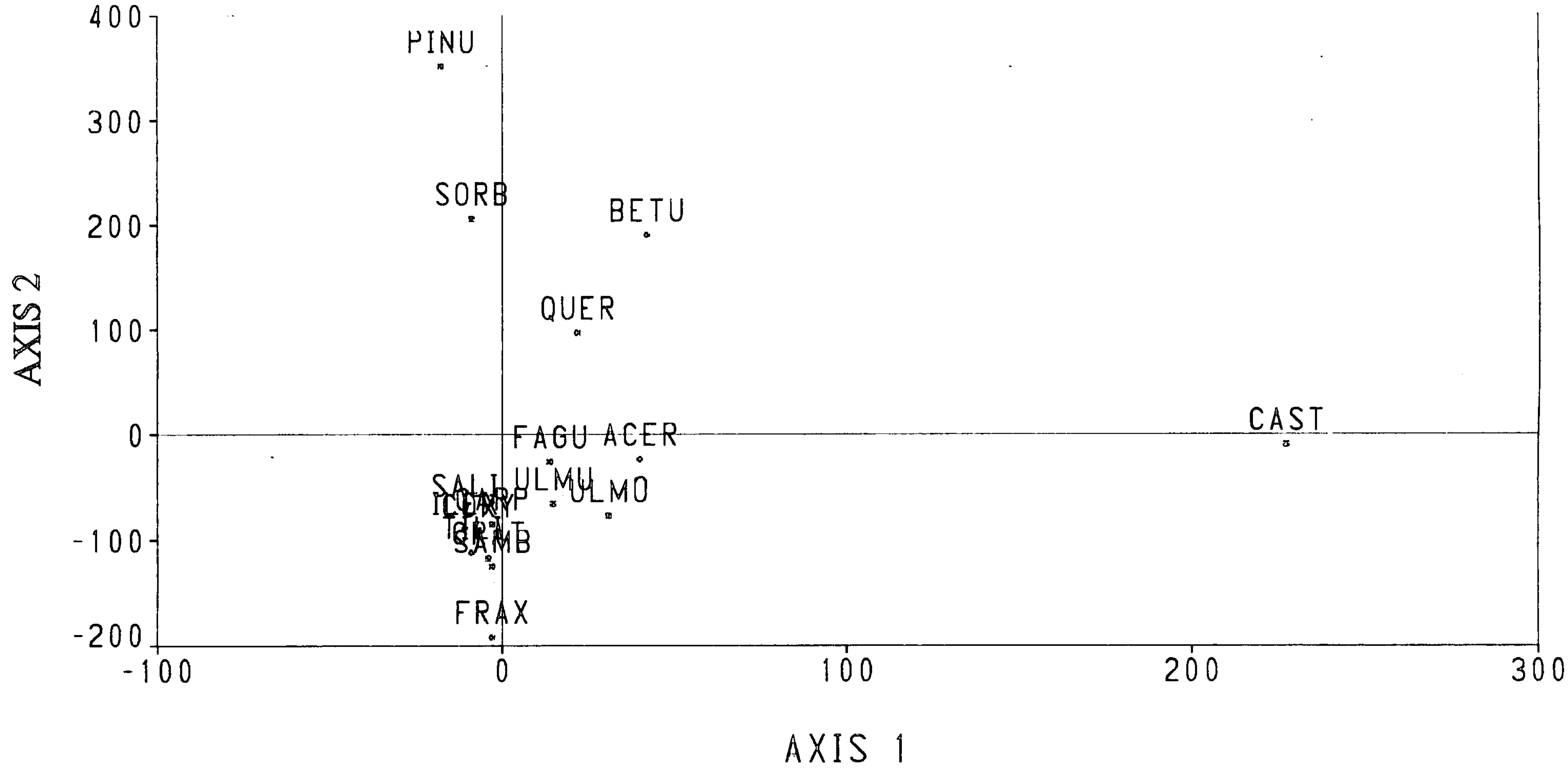
The Frankland Upper Viaduct station was removed in the analysis due to collinearity in the data. On examination of the raw data, this station was seen to have a similar canopy composition to the Rainton Monoculture station and as such could be replaced in the data by this station.

The species determined as outliers in the DCA analysis (Graph 1) were *Pinus nigra*, *Corylus avellana*, *Tilia cordata*, *Salix cinerea*, *Castenea sativa* and *Ulmus procera* (for density, frequency and basal area), all of which occurred in only a few PCQ's. The samples which were outliers were those at the Rainton Pine station, where the high proportion of *Pinus nigra* was biasing the analysis, and also quadrat one at the Lower Viaduct station in Frankland Wood (Graph 2). This sample was removed due to high proportion of *Castenea sativa* present.

It was also determined in the analysis that the density of *Ulmus procera* was influencing the data set, however, this species was not removed for the second DCA run since neither the frequency nor the basal area of that species were outliers.

The species and samples determined as outliers during the first analysis were downweighted during a second DCA to remove the effect of these species and samples from the analysis. No outliers were determined by the second DCA analysis and the four sample axes were placed in the CANOCO environmental file.

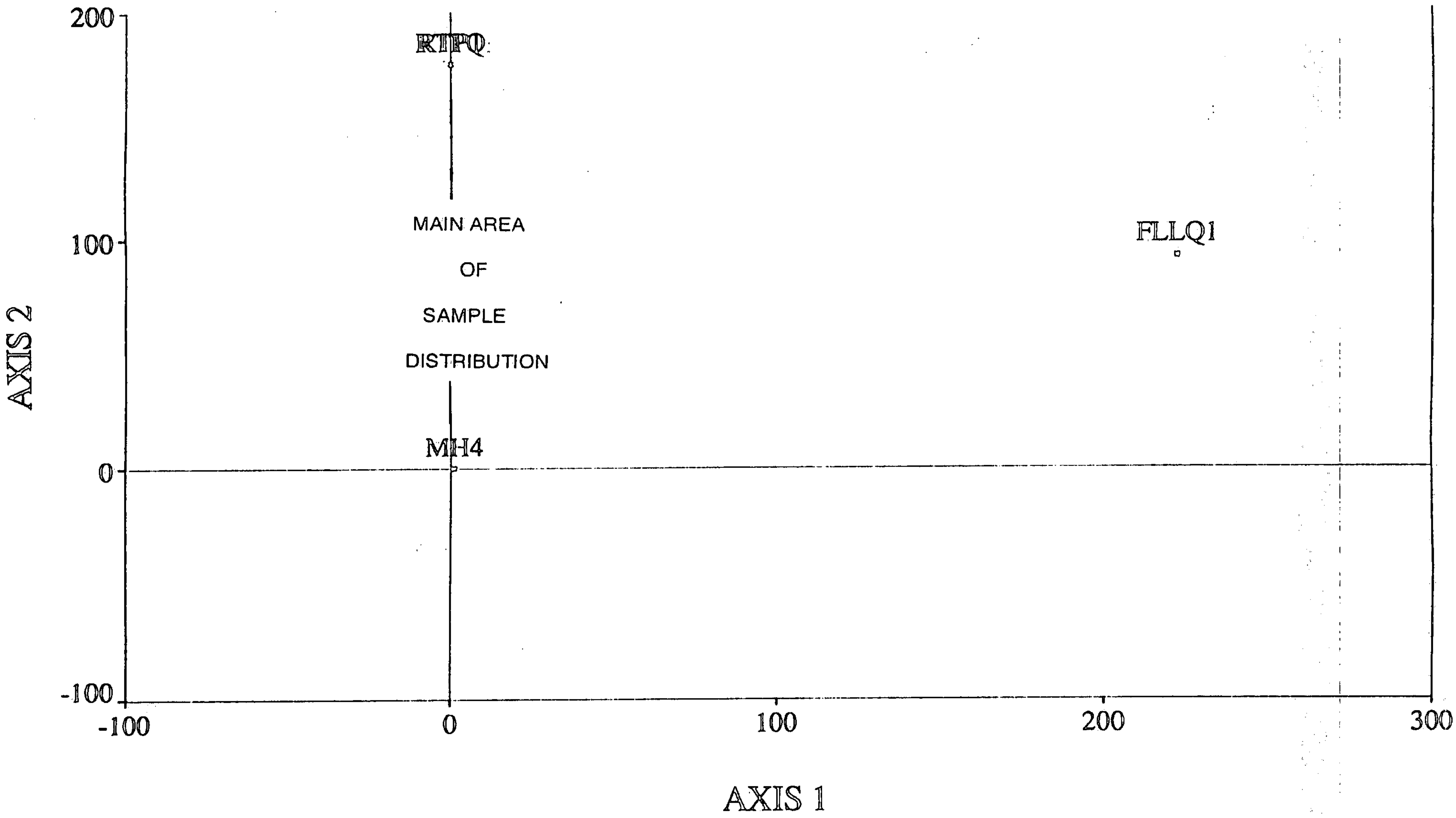
Graph 1 : Showing Species outliers as determined by DCA analysis.



Note:Other species in text were noted as outliers using other DCA axes

Note:Graph has been simplified by using frequency data only

Graph 2 : Showing sample outliers as determined by DCA analysis.



EIGENVALUES

Table 8 : DCA Eigenvalues.

AXIS	EIGENVALUE - DCA 1	EIGENVALUE - DCA 2
1	0.77163	0.12437
2	0.23233	0.05883
3	0.07260	0.04055
4	0.05161	0.02751

From Table 8 it can be seen that the eigenvalues (which are a measure of separation of the species' distributions along the ordination axis) for the second DCA are substantially lower than those for the first. This is due to the downweighting of those species and samples which were strongly influencing the analysis.

The first axis of ordination in the second DCA is still considered to be substantially more important than the second. In the first DCA it is three times more important than the second, while in the second run it is still double the second axis. The proportions between the first two axes on the second DCA run remain comparable with the first run.

C:4 CCA ANALYSIS

CCA analysis was undertaken on the species and environmental files. The results from the first run were unsatisfactory since many of the stations together with the cosine of the aspect had high Variance Inflation Factors and as such would have had to be ignored in any future analysis (Appendix 3). Large VIF's (i.e. those over 20) indicate that variables are almost perfectly correlated with each other and have no unique contribution to the regression equation, and thus do not merit interpretation (Ter Braak 1987). Six of the ten stations had large inflation factors and thus would have to be ignored. This would have greatly reduced the scope of this study. In order to reduce the inflation factors, one or more of the environmental variables may be removed in order to make the rest of the data significant (Ter Braak 1987).

The cosine of the aspect was removed in a second CCA analysis since this was the only environmental variable which was not significant in the first run. This reduced all the inflation factors to well below 20, making all the stations significant to the study. In examining the results further it was seen that the sine of the aspect was not significant to the regression (by examining the T-value for this variable). Since neither the sine nor the cosine of the aspect could be used in further discussion, CCA was rerun, removing both these variables from the analysis. The VIF values remained significant for all the environmental variables. The results from the third CCA analysis form the rest of these results.

A Monte Carlo Permutation Test was run on the CANOCO analysis using 99 permutations which determined that all the axes of variation were statistically significant at the 0.01% level. Thus the species are significantly related to the measured environmental variables. As with the DCA analysis, the Frankland Upper Viaduct station was removed due to collinearity.

EIGENVALUES

Table 9 : Eigenvalues for the third CCA.

AXIS	EIGENVALUE
1	0.4753
2	0.2789
3	0.2217
4	0.1858

The first axis is the most important axis, with an eigenvalue almost twice that of the second axis. The third axis is of similar importance as the second. Although the Eigenvalue for the fourth axis is also quite high it was decided that it would not be examined further as no discernible patterns could be seen on examination of the significant variables and the species-environmental biplots. The variance accounted for by this axis is also very low compared to the other axes (Table 10).

VARIANCE

Table 10 : Percent Variance Accounted For By The Species-Environment Biplot.

AXIS	PERCENTAGE
1	22.7
2	13.3
3	10.6
4	8.9

Only about half the variance (55.5%) is accounted for by the four axes from the CCA analysis, however this is quite normal, since part of the total variance is due to noise in the data from other environmental variables which have not been measured in this study (Ter Braak 1988).

T-VALUES

Table 11 : T-Values for the CCA Analysis.

The cut off value for significance at the 5% level for the data is 2.1 with 48 degrees of freedom. The T-values show the significance of the variables to the regression.

VARIABLE	AXIS 1	AXIS 2	AXIS 3	AXIS 4
MOORHOUSE	1.37	-4.48	-2.22	4.48
MALLYGILL	1.21	-2.94	-2.96	3.96
RAINTON MONO	1.32	-4.95	-1.05	2.29
RAINTON PINE	1.15	-4.32	-1.07	1.72
RAINTON SLOPES	1.86	-4.91	-2.14	5.24
MIDMALLY	0.03	-2.20	-3.30	3.44
FRANKLAND SOUTH	1.30	-2.14	-2.09	3.35
FRANKLAND CENTRAL	3.01	-4.42	-1.24	1.45
LOWER VIADUCT	2.03	-1.23	-0.43	1.17
LOAM	-4.13	3.93	1.14	3.84
pH	7.65	3.89	-1.04	0.82
SLOPE	-0.68	-1.85	-1.00	-0.25
DCA 1	-0.63	0.28	3.50	-0.43
DCA 2	1.72	-3.81	-0.18	2.29
DCA 3	-0.42	1.32	0.30	-4.71
DCA 4	0.10	2.49	2.15	0.79

The Lower Viaduct station and the slope variable are not significant on any axis. The third DCA axis is also insignificant to the study since it is only significant on the fourth CCA axis which has already been removed from this investigation. From earlier analysis it was also seen that the aspect of the stations was not significant. This indicates that species distribution is independent of slope and aspect.

The T-values show that loam, pH and Frankland Central are significant on the first axis. The significance of soil type and pH on the first CCA axis indicates that soil conditions are the most important factor in determining species composition. The reason for Frankland Central being significant on this axis is unknown, however, the peculiarity of this woodland has already been seen in past analysis (the wide pH ranges found at the Lower Viaduct station).

The significant variables on axis 2 are the remaining stations, the second and fourth DCA axes, loam and pH. Soil conditions are important in describing the species distribution along this axis, together with the site history (since the names of the stations also represent differing management regimes) and the canopy composition. Two DCA axes can be used to describe the species distribution along this axis. It is interesting to note that the second and fourth DCA axes are significant in describing the ground flora, rather than the first. Although the first axis best describes the canopy composition, it is not the most important axis in describing the relationship between the canopy, ground flora and other environmental variables. On examination of the effects of the significant DCA axes (2 and 4) in the species-environmental biplots it can be seen that they are acting in opposite directions, in effect acting as points along a single axis.

The significant stations on the third CCA axis are Moorhouse, Mallygill, Rainton Slopes and Midmally. These are all stations which are actively managed. The second and the fourth DCA axes are also significant on this axis. Thus it appears that the species composition of those sites which are actively managed can be explained by their canopy composition along this axis.

BIPLOTS

This study aims to examine the overall relationship between the management (as shown by the overstorey composition) of a particular site and the ground flora species found within. The biplots between the species and the environmental conditions have not been included in this study since these relationships have already been investigated by other authors (e.g. Ovington, Pearsall). For the sample/environment biplots the centroid scores for each station instead of using individual quadrat scores, since the centroid scores are an average of all the quadrat scores within each station.

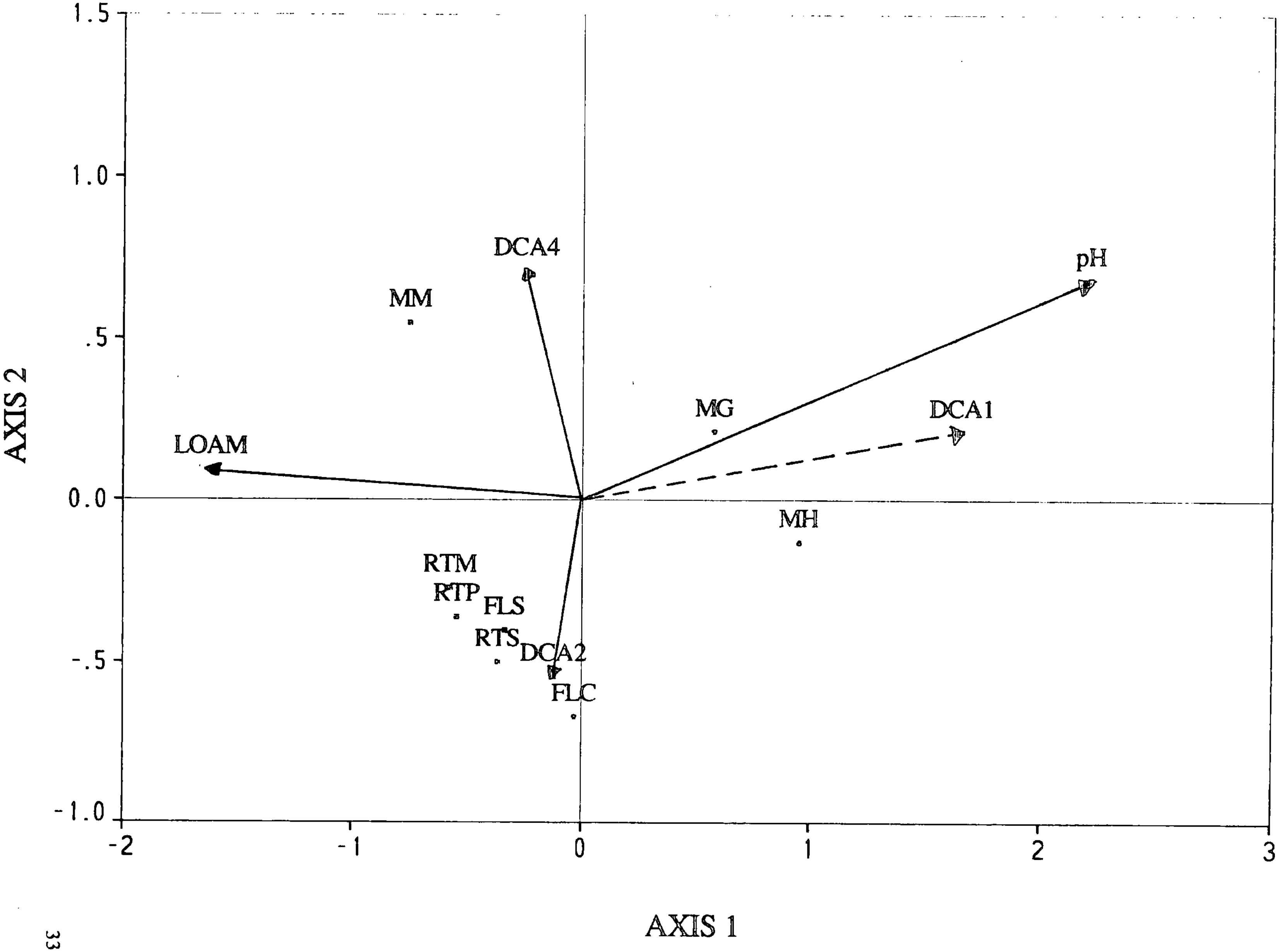
The environmental variables and stations were initially plotted at the same scale, but the results were unclear due to crowding in the data. The environmental variables were multiplied by a factor of five to make the graphs clearer. Those environmental variables which were not significant on any of the first three CCA axes, or had previously been removed from the analysis were not plotted on the biplots (i.e. slope, aspect, lower viaduct, upper viaduct and the third DCA axis).

Those significant variables with the longest arrows are having the greatest effect on the stations which are plotted on each biplot.

Table 12 BIPLOT GRAPHS LEGEND

Variable Labels	**Meaning**
MH	Moorhouse
MG	Mallygill
RM	Rainton Mono
RP	Rainton Pine
RS	Rainton Slopes
MM	Midmally
FLS	Frankland South
FLC	Frankland Central
LOAM	Loam
pH	pH
DCA1	DCA axis 1
DCA2	DCA axis 2
DCA4	DCA axis 4

Graph 3 : CCA Station biplot Axis 1 against Axis 2.



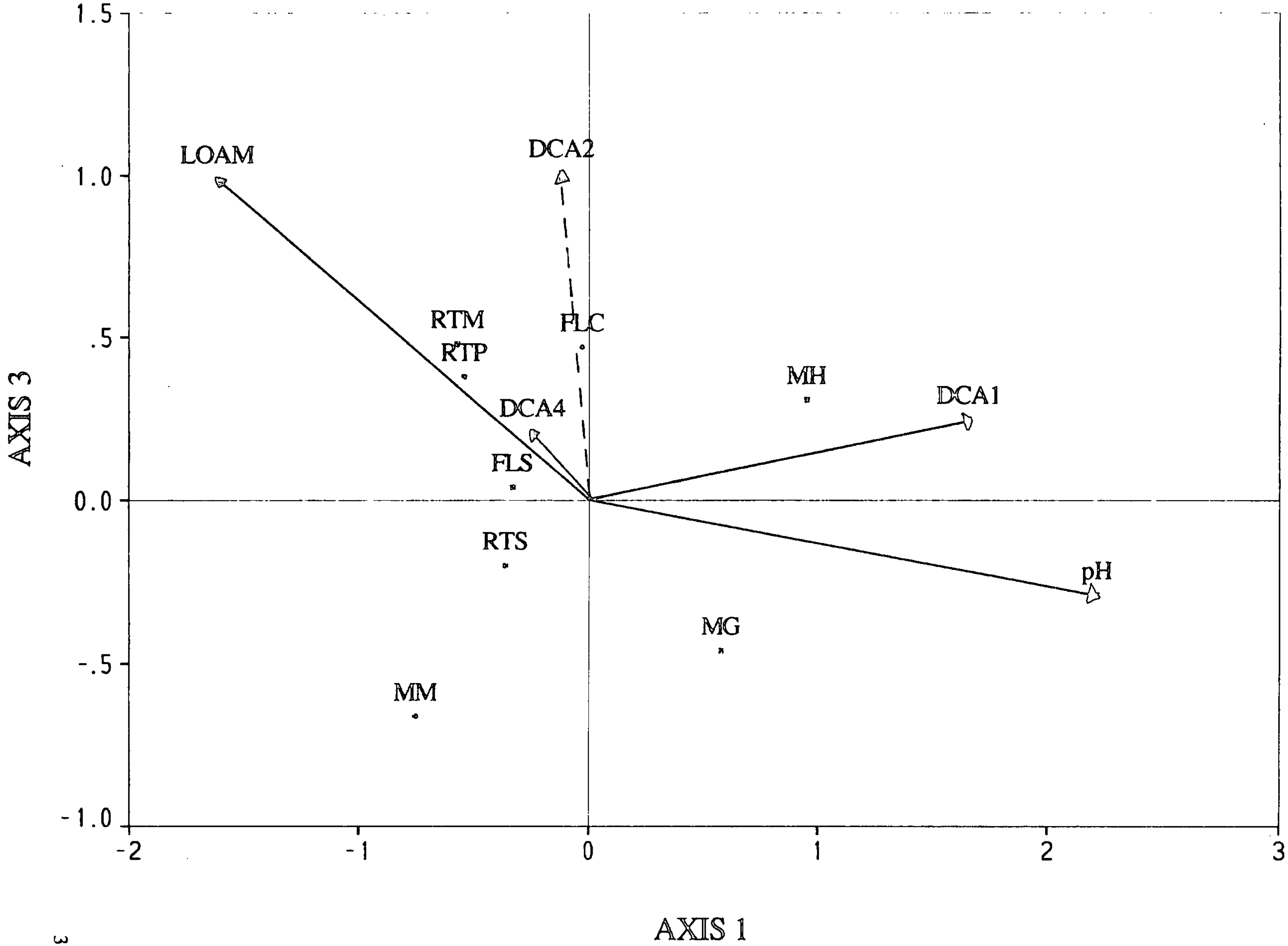
Arrow heads represent environmental variables X5.
——— =SIGNIFICANT VARIABLES.
- - - - =INSIGNIFICANT VARIABLES.

Summary of Graph 3

This graph shows those variables which are having a significant effect on the stations along the most important CCA axes. Of the significant variables on this graph, it can be seen that the soil pH is having the greatest effect, since this variable has the longest arrow. Loam and pH are almost opposite in their effects on the samples, confirming the earlier findings that loamy soils have a lower pH than clayey soils. The stations which have samples with the highest pH are on the positive side of the graph, with the samples at the Mallygill station most strongly linked to pH. The Midmally station would also be expected to be highly correlated with high pH, since the station contains some areas of clayey soil. This station occurs on the negative side of the graph indicating that soil pH is not the major factor in determining species content. This station is also affected by the fourth DCA axis, indicating that the canopy is also influencing the species composition at this station.

The Moorhouse station is also linked not only with pH but is also affected by a canopy axis, but in this case by the first DCA axis. The Rainton Mono and Rainton Pine stations are most dominantly affected by low pH, while Frankland Central and Rainton Slopes appear to be closely associated with the second DCA axis. On examination of this and subsequent graphs it can be seen that Frankland Central always has a close association with the second DCA axis. It is likely that the dominance of this variable at this station has caused the station to be significant in the CCA analysis.

Graph 4 : CCA Station biplot Axis 1 against Axis 3.



Arrow heads represent environmental variables X5.
—— = SIGNIFICANT VARIABLES.
– – – = INSIGNIFICANT VARIABLES.

Summary of Graph 4

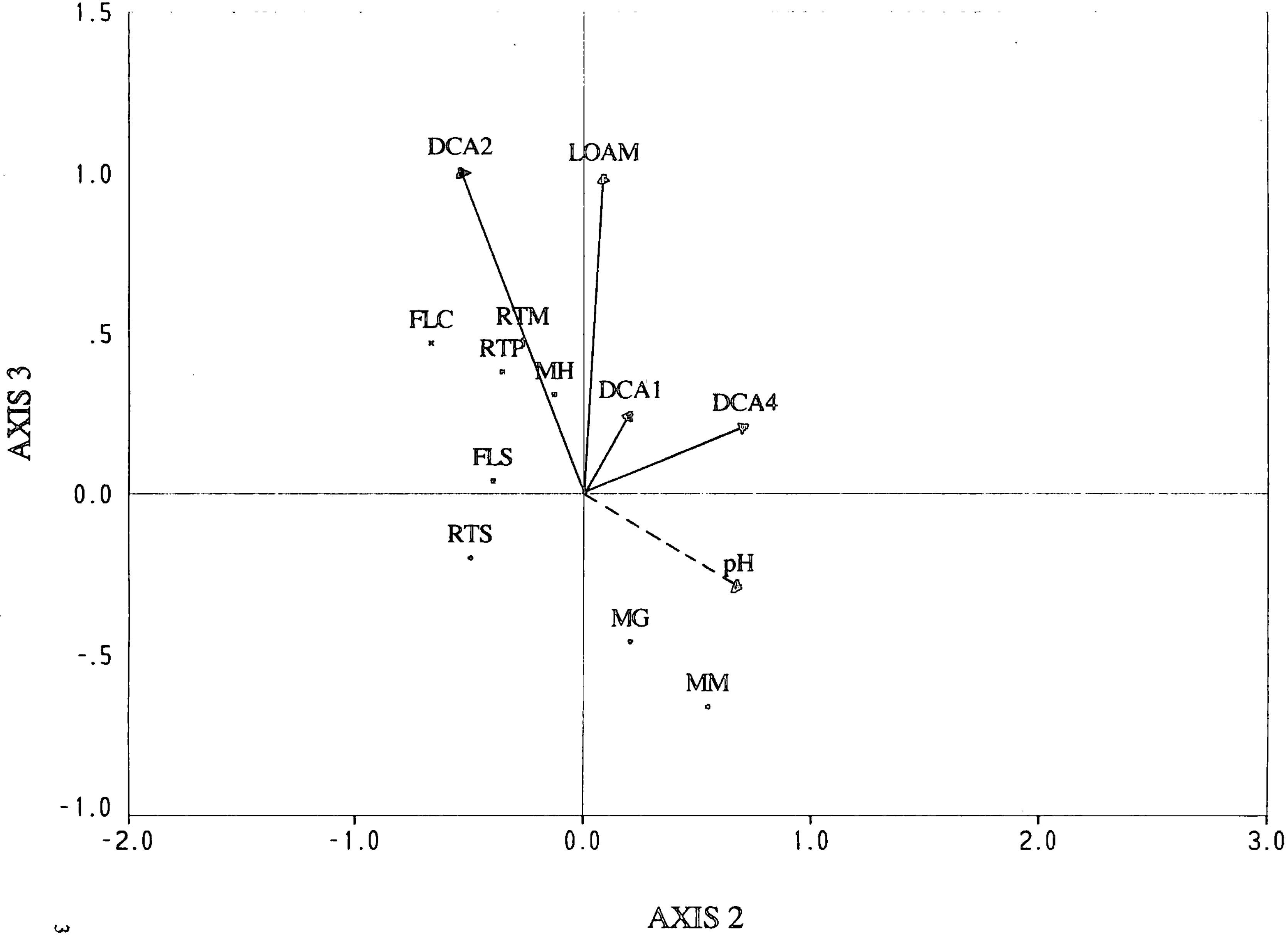
This graph shows the relationship between the first and third CCA axes. It can be seen that soil conditions (pH and soil type) are still the dominant factors influencing the stations, and thus on their species composition. Moorhouse and Mallygill are again situated on the positive side of the graph, though Mallygill is associated with negative loam (i.e. clayey) soil instead of high pH, but the relationship between these two variables has already been seen. Moorhouse has been repeatedly associated with the first DCA axis, indicating a close relationship with this variable. The Rainton Mono and Rainton Pine stations are still grouped together, indicating that the presence of conifers is having little effect in comparison to other environmental factors (such as the loamy soil conditions found at these stations, which is the greatest influencing factor on these station on this graph).

The distribution of species found at the Frankland South station is most influenced by the low pH conditions found at this station, while Rainton South is influenced by the canopy composition (the first DCA axis). The Midmally station, although partially influenced by clayey conditions, is most affected by the first DCA axis, though these associations are not strong.

Summary of Graph 5

This graph is not particularly useful, since the effects of the environmental variables are much reduced in this graph in comparison to the other graphs. The most dominant variables on this graph are loam and the second DCA axis, with the Rainton Mono, Rainton Pine, Moorhouse, Midmally and Mallygill stations associated with DCA2. The Rainton Slopes station is associated with the fourth DCA axis, while Frankland Central is associated with low pH.

Graph 5 : CCA Station biplot Axis 2 against Axis 3.



Arrow heads represent environmental variables X5.

—— = SIGNIFICANT VARIABLES. - - - - = INSIGNIFICANT VARIABLES.

D : DISCUSSION

The pH analysis undertaken during this study have indicated that there is a reduction in the range of pH values found in soils under plantations, with the greatest restriction occurring under conifer plantations. The soils under plantations, in general, were also found to be more acidic than soils under different management regimes, with conifer plantations having the most acidic soil. The acidification of soils under conifer plantations is well known, however, the acidification of the soil under deciduous plantations is less well documented, Ovington (1953) found a reduction in soil pH under *Quercus* plantations but did not detect any restriction in the range of pH values under plantations. This restriction is an interesting finding, since the reduction in the range of soil pH values within a woodland can be compared to reducing the number of habitats present and the expected result of this would be a reduction in the number of species present.

Pearsall (1938) has stated that when relating plant communities to soil pH, the most important factor is that the soil has not recently been disturbed and that the associated vegetation is well established. The soils in the plantation woodlands and the woods which have been actively managed will have undergone a lot of disturbance, while most of the soil profiles of Frankland wood will be relatively undisturbed. The degree of disturbance and the time passed since the disturbance has taken place are important in determining at which stage of recovery the soils are at the present time. Mechanical disturbance due to clearance and the planting of new trees and the building of the viaduct, for example, may result in the release of nutrients from the lower layer of the soil profile, which may take many years to return to previous levels, or not at all, thus the pH results from this study can only be taken as an indication of the soil conditions.

The result of species distribution being independent of slope and aspect in this study is surprising since other authors have commented on the relationship between species distribution and these environmental variables (e.g. Whitney & Foster 1988). The slope varied from flat (0 degrees) to 55 degrees, however most of the sites were between 0 and 25 degrees. The aspect of the stations was also very limited, with most of the stations facing south east to south west. It is likely that these variables were not significant due to the limited range of the variables found in the woodlands of this survey.

pH analysis has indicated that clayey soils have a higher pH than loamy soils, a result which is to be expected considering the nature of these soils. Those stations which contained areas of both types of soil were more interesting floristically, having a greater diversity of species than those stations which had only loamy soils. Unfortunately none of the stations were based on only clayey soils, but it is considered that these stations would also have a lower number of species present than those stations containing both soil types. CCA analysis indicated that the most important factors determining species distribution were soil type and pH. Cooper (1985) has shown that soil texture is a key factor influencing the ground flora, mainly through its influence on soil water status and acidity. This study confirms his findings.

The suggestion of a reduction in species diversity under plantations is confirmed by ground flora analysis, where it could be seen that plantation woodlands (with their reduced range in pH values) had a much lower number of ground flora species present when compared with other management types. The ground flora of the plantation woodlands had little ecological value, consisting of a monotonous sward of vegetation with little understorey present. The woods which had been actively managed for conservation purposes had the greatest number of both ground flora and understorey species and contained a rich and varied ground flora and understorey community. Those woodlands which had not been managed for some time were fairly poor floristically, but these areas were of interest due to the diversity found in the canopy, understorey and parts of the ground vegetation.

Dzwonko (1993) has suggested that the floristic composition of young woodland communities can be fully developed if the woods are situated adjacent to ancient woodlands. From this study it can be seen that this has not yet occurred, since the number of species present in the young plantation woodlands was much lower than those found in the adjacent ancient woodlands. Rainton Mono, a *Quercus* plantation had only seventeen understorey and ground flora species, while the adjacent ancient woodland area of Midmally had thirty two. The Upper Viaduct plantation had a total of nine species present, while the Lower Viaduct station had twenty five. The plantation woodlands are still fairly young, being only around fifty years old and it can be assumed that the number of species will increase over time, however, I believe that it is unlikely that the number of species will increase to a similar level to that found in the ancient woodland sites.

It is more likely that the ancient woodlands will remain richer than recent woods indefinitely, as suggested by Peterken & Game (1984). They suggest that agricultural intensification in the surrounding land, coupled with soil changes and isolation in time and space from older woodlands will continue to influence the species composition of recent woodlands, resulting in fewer species in these woodlands.

The effects of differing canopy types in plantations was also examined during this study, comparing *Pinus nigra* with *Quercus petraea* plantations. The results from this study have indicated that there is an even greater reduction in the number of species under conifers compared to broadleaf plantation with the number of species within Rainton Pine being less than a third of the number found in the adjacent oak plantation. Pigott (1990) also found a reduction in the number of species within the field layer. He suggested that the vernal species, such as *Anemone nemorosa* and *Allium ursinum*, would suffer the greatest reduction due to the lower light levels found under an evergreen canopy in the early months of the year. The only vernal species found within the pine plantation was *Hyacinthoides non-scripta*, which would agree with Pigott's suggestion, however, there were also few vernal species found under the broadleaf plantations.

The most likely causes of the reduction in the number of vernal species under plantations are the disturbances which occur during the process of clearance and uprooting stumps for plantation of new trees (O'Leary 1985) (reducing the number of viable seeds in the seed bank), and the increased shading which occurs during the early stages of plantation due to the trees being planted close together. Once thinning of the overstorey has taken place, under broadleaves, light conditions in the early months of the year increase, allowing germination of any seed remaining in the seed bank. Conifers develop a very dense canopy, under which the ground flora is usually completely destroyed at the thicket or early pole stage. After around twenty five years, due to the canopy thinning and the removal of some of the trees the ground vegetation begins to invade the forest floor (Ovington 1955).

The trees in the woods which are managed for conservation are, in the main, allowed to regenerate naturally which permits not only the maintenance of similar conditions for the established ground flora, but also increases species and age structure diversity. Continual management results in the disturbance of the soil and maintains species richness A natural woodland has a mosaic of trees at different heights and in different age classes, resulting in a structurally diverse community.

Plantation woodlands consist of an even aged stand, with little or no understorey. Natural woodlands contain open areas due to tree fall which increase the openness of the wood, allowing light to penetrate to the forest floor for several seasons. This allows new woodland species to colonise and establish and also allows the germination of the seed bank in the area. In a plantation, the only open areas are where trees are removed and the canopy from the remaining trees quickly grow to close the gap, which greatly reduces the probability of any regeneration, recolonisation or germination taking place, though high densities of persistent seed may remain (Pigott 1990).

The dominant ground flora species of the plantation woodlands were grasses, particularly *Holcus mollis* and *Deschampsia flexuosa*. It has been demonstrated by Pearsall (1938) that both these species can form a dense mat of leaf bases which is often impenetrable. It is likely that these grasses became dominant during the early stages of woodland development and their presence has hindered the regeneration of both the vernals and other characteristic woodland species. Since a pool of species quickly establishes to which there is effectively no later addition (Peterken & Jones 1989) the dominance of these species in the early stages would greatly affect the species composition. Ford & Newbould (1977) found that only one species (*Dryopteris filix-mas*) was able to colonise the woodland floor once the canopy had closed.

The type of management practised in each of the different woodlands has been shown to influences the floral composition with the different management types resulting in different levels of disturbance within the woods. The plantation woods have been highly disturbed, coupled with increased acidity has resulted in a much simplified ground flora. The 'hands off' method of management practised in most parts of Frankland Wood has resulted in low floral diversity, however, the resulting woodland does appear natural. The woods in the Moorhouse complex are actively managed to promote a structurally diverse community and contains a greater number of trees and understorey species than the largely unmanaged wood of Frankland.

The management policies of the woods in County Durham very much depend on the position and type of woodlands present. Woods which are managed for timber production should ideally be positioned in areas where there are few visitors since there is little of ecological interest present. Woodlands which are not managed for timber and are accessible to visitors should be actively managed as this results in a wide variety of woodland species, creating an attractive woodland environment. Woodlands which are relatively inaccessible or visited infrequently are most economically managed by a hands off approach. This results in a natural looking woodland, even if there is a limited ground flora present.

Under ideal conditions, this survey would have been undertaken in a homogenous woodland, with examination of pH and vegetation, taken at regular intervals over the year to include the different seasons. These surveys would continue for at least one year prior to any disturbance, preferably using permanent quadrats. Close monitoring on a long term basis could then provide detailed information on the types of changes which could be expected as a result of differing management policies (Ovington 1964).

APPENDICES

&

BIBLIOGRAPHY

APPENDIX 1 Environmental Variables for each Station.

Moorhouse

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	clayey	5.2	-	-
Quad 2	loamy	4.4	-	-
Quad 3	clayey	5.7	-	-
Quad 4	clayey	5.0	-	-
PCQ 1	clayey	4.0	-	-
PCQ 2	loamy	4.7	-	-
PCQ 3	clayey	4.8	-	-
PCQ 4	loamy	7.2	-	-
PCQ 5	clayey	5.6	-	-

Mallygill

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	3.9	10	230
Quad 2	loamy	4.5	50	230
Quad 3	clayey	6.4	40	130
Quad 4	loamy	4.5	35	130
Quad 5	clayey	6.2	40	200
PCQ 1	clayey	4.6	50	130
PCQ 2	clayey	5.1	55	130
PCQ 3	clayey	5.7	50	230
PCQ 4	loamy	4.2	45	230
PCQ 5	loamy	4.3	50	200

Rainton Monoculture

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	4.0	-	-
Quad 2	loamy	4.0	-	-
Quad 3	loamy	3.8	-	-
Quad 4	loamy	4.1	-	-
PCQ 1	loamy	4.1	-	-
PCQ 2	loamy	4.2	-	-
PCQ 3	loamy	4.1	-	-
PCQ 4	loamy	4.0	-	-
PCQ 5	loamy	4.1	-	-

Rainton Pine

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	4.0	-	-
PCQ 1	loamy	4.2	-	-

Rainton Slopes

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	3.9	20	200
Quad 2	loamy	3.8	25	200
Quad 3	loamy	3.8	20	200
PCQ 1	loamy	3.9	20	200
PCQ 2	loamy	4.6	15	200
PCQ 3	loamy	4.2	25	200
PCQ 4	loamy	4.8	20	200
PCQ 5	loamy	3.8	20	200

Midmally

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	4.0	20	200
Quad 2	loamy	3.9	30	200
Quad 3	clayey	4.8	25	200
Quad 4	loamy	4.6	30	200
Quad 5	loamy	3.8	35	200
PCQ 1	loamy	4.0	20	200
PCQ 2	clayey	5.2	25	200
PCQ 3	clayey	3.9	15	200
PCQ 4	clayey	5.5	45	200
PCQ 5	loamy	4.4	55	200

Frankland South

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	3.9	50	165
Quad 2	loamy	4.3	40	165
Quad 3	loamy	4.0	25	165
PCQ 1	loamy	3.8	55	165
PCQ 2	loamy	3.9	50	165
PCQ 3	loamy	4.4	10	165

Frankland Central

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	4.0	20	80
Quad 2	loamy	3.8	10	80
Quad 3	loamy	3.7	10	80
Quad 4	loamy	3.8	10	80
PCQ 1	loamy	3.9	15	80
PCQ 2	loamy	4.0	10	80
PCQ 3	loamy	4.0	30	80

Lower Viaduct

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	5.3	5	60
Quad 2	loamy	3.8	10	60
PCQ 1	loamy	4.1	25	60
PCQ 2	loamy	3.8	5	60

Upper Viaduct

Quadrat surveyed	Soil type	pH	Slope (°)	Aspect (°)
Quad 1	loamy	3.6	5	60
PCQ 1	loamy	3.8	10	60
PCQ 2	loamy	4.0	10	60

APPENDIX 2 : STATION SPECIES LISTS

Note : * denotes tree/understorey species.

Moorhouse

Agrostis stolonifera
Anemone nemorosa
Arum maculatum
Brachythecium rutabulum
Carpinus betulus *
Cirriphyllum piliferum
Conopodium majus
Corylus avellana *
Crataegus monogyna *
Dryopteris dilatata
Eurhynchium praelongum
Galium aparine
Geranium robertianum
Geranium sylvaticum
Geum urbanum
Hedera helix
Holcus lanatus
Holcus mollis
Hyacythoides non-scripta
Lolium perenne
Lonicera periclymenum *
Mercurialis perennis
Milium effusum
Mnium hornum
Oxalis acetosella
Plagiothecium sp.
Quercus petraea *
Ranunculus ficaria subsp. ficaria
Rosa canina
Rubus fruticosus agg.
Sorbus aucuparia *
Stellaria graminea
Taraxacum officinale
Urtica dioica
Veronica montana
Viola riviniana

Mallygill

Acer pseudoplatanus *
Aegopodium podograria
Agrostis stolonifera
Allium ursinum
Anemone nemorosa
Carpinus betulus *
Cirriphyllum piliferum
Crataegus monogyna *
Deschampsia flexuosa
Dryopteris carthusiana
Dryopteris dilatata
Eurhynchium praelongum
Eurhynchium striatum
Fagus sylvatica *
Fraxinus excelsior *
Galium aparine
Galium odoratum
Geranium robertianum
Lapsana communis
Lonicera periclymenum *
Luzula sylvatica
Melica uniflora
Mercurialis perennis
Milium effusum
Mnium hornum
Myosotis sylvatica
Oxalis acetosella
Plagiothecium sp.
Potentilla sterilis
Primula veris
Pteridium aquilinum
Quercus petraea *
Ranunculus ficaria subsp. ficaria
Rosa canina
Rubus fruticosus agg.
Rumex sanguineus

Mallygill cont...

Geum urbanum
Hedera helix
Holcus lanatus
Holcus mollis
Hyacythoides non-scripta
Ilex aquifolium *
Sambucus nigra *
Sorbus aucuparia *
Stachys palustris
Stellaria graminea
Ulmus procera *
Veronica montana

Rainton Mono

Acer pseudoplatanus *
Deschampsia flexuosa
Dicranella sp.
Dryopteris carthusiana
Dryopteris dilatata
Fraxinus excelsior *
Galium aparine
Hedera helix
Holcus mollis
Lonicera periclymenum *
Milium effusum
Oxalis acetosella
Pteridium aquilinum
Quercus petraea *
Rosa arvensis
Rosa canina
Rubus fruticosus agg.

Rainton Pine

Holcus mollis
Hyacythoides non-scripta
Pteridium aquilinum
Quercus petraea *
Rubus fruticosus agg.

Rainton Slopes

Acer pseudoplatanus *
Agrostis stolonifera
Betula pendula *
Brachythecium rutabulum
Crataegus monogyna *
Deschampsia flexuosa
Dryopteris carthusiana
Dryopteris dilatata
Galium aparine
Geum urbanum
Hedera helix
Holcus lanatus
Holcus mollis
Ilex aquifolium *
Lonicera periclymenum *
Luzula sylvatica
Milium effusum
Mnium hornum
Oxalis acetosella
Pteridium aquilinum
Quercus petraea *
Rubus fruticosus agg.
Sorbus aucuparia *
Stellaria graminea
Stellaria media

Midmally

Acer pseudoplatanus *
Allium ursinum
Anemone nemorosa
Atrichum cuspidatum
Betula pendula *
Blechnum spicant
Brachythecium rutabulum
Bromus ramosus
Carpinus betulus *
Crataegus monogyna *
Deschampsia cespitosa
Deschampsia flexuosa
Dryopteris carthusiana
Dryopteris dilatata
Eurhynchium striatum
Fagus sylvatica
Galium aparine
Hedera helix
Holcus mollis
Hyacinthoides non-scripta
Ilex aquifolium *
Lonicera periclymenum *
Luzula sylvatica
Oxalis acetosella
Plagiothecium sp.
Pteridium aquilinum
Quercus petraea *
Rosa canina
Rubus fruticosus agg.
Rumex acetosella
Sambucus nigra *
Stachys palustris
Teucrium scorodonia
Vaccinium myrtillus

Frankland South

Brachythecium rutabulum
Cirriphyllum piliferum
Dryopteris carthusiana
Dryopteris dilatata
Eurynchium praelongum
Fagus sylvatica *
Holcus lanatus
Holcus mollis
Hyacinthoides non-scripta
Ilex aquifolium *
Lonicera periclymenum *
Luzula sylvatica
Milium effusum
Pteridium aquilinum
Quercus petraea *
Rubus fruticosus agg.

Frankland Central

Acer pseudplatanus *
Dryopteris dilatata
Fagus sylvatica *
Galium aparine
Geranium robertianum
Hedera helix
Holcus mollis
Hyacinthoides non-scripta
Ilex aquifolium *
Lonicera periclymenum *
Milium effusum
Oxalis acetosella
Pteridium aquilinum
Rubus fruticosus agg.
Stellaria holostea
Urtica dioica

Frankland Lower Viaduct

Blechnum splicant
Castenea sativa *
Cirriphyllum piliferum
Deschampsia flexuosa
Digitalis purpurea
Fagus sylvatica *
Galium aparine
Geranium robertianum
Geum urbanum
Hedera helix
Heracleum sphondyllium
Holcus mollis
Hyacinthoides non-scripta
Lonicera periclymenum *
Mercurialis perennis
Milium effusum
Mnium hornum
Oxalis acetosella
Pteridium aquilinum
Quercus petraea *
Rubus fruticosus agg.
Rumex sanguineus
Sambucus nigra *
Veronica montana

Frankland Upper Viaduct

Acer pseudoplatanus *
Cirriphyllum piliferum
Deschamspia flexuosa
Fagus sylvatica *
Holcus mollis
Lonicera periclymenum *
Pteridium aquilinum
Sorbus aucuparia *

APPENDIX 3 : Variance Inflation Factors (VIF) from the first CCA run.

STATION	VIF
Moorhouse	28.7805
Mallygill	124.6661
Rainton Mono	15.4719
Rainton Pine	4.0765
Rainton Slopes	111.6294
Midmally	123.2626
Frankland South	64.1916
Frankland Central	9.5907
Lower Viaduct	3.9283
Upper Viaduct	REMOVED due to collinearity
Loam	2.7508
pH	3.7145
Slope	4.8539
Sine Aspect	3.8684
Cosine Aspect	125.1319
DCA1	5.1025
DCA2	3.6585
DCA3	2.7557
DCA4	1.5056

Note : High VIF's (i.e. those over 20) cannot be used in any future analysis. The sine of the aspect was removed in a second CCA run, and then the cosine of the aspect was also removed in a third run. The VIF's from this analysis are as follows.

VIF's from the third CCA analysis.

SITE	VIF
MOORHOUSE	11.47
MALLYGILL	15.30
RAINTON MONO	5.75
RAINTON PINE	2.02
RAINTON SLOPES	9.14
MIDMALLY	8.05
FRANKLAND SOUTH	5.40
FRANKLAND CENTRAL	4.83
LOWER VIADUCT	3.91
LOAM	2.59
pH	3.25
SLOPE	4.81
DCA 1	4.40
DCA2	3.25
DCA 3	2.73
DCA 4	1.43

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